INDEX

Aarnoudse, J., 345 Abel, J. F., 104, 105, 183, 328, 329 Aimond, F., 23, 24, 43 Air terminal, St. Louis, 268, 272, 333 Airport hangar, Seattle, 340-342 Allen, J. E., 42, 217 Alspaugh, D. L., 138 American Concrete Institute (ACI), 24, 256 Committee 334 (joint committee with ASCE) on Concrete Shell Design and Construction, 321, 323 Committee 344 report on "Design and **Construction of Circular Prestressed** Concrete Structures," 155, 183, 321 American Society of Civil Engineers (ASCE), 16 Committee on Masonry and Reinforced Concrete, 21 joint committee with ACI 334 on concrete shell design and construction, 323 Manual 31, 203, 205, 210, 257 Task Force Committee on Folded Plates, 1963 report of, 291, 296 Ammann, O., 20 Ammann and Whitney, 20 Analysis: approximate methods of (see Simplifications) for buckling, 311-316, 320-321 for circular cylindrical shell walls, 76 with fixed base, 87, 89 with free-sliding base, 87 with hinged base, 87-88 with partially fixed base, 89-92 with partially sliding base, 87 with roof slab, 78-86 (See also for domes, below) by classical theory, 36-37, 311

Analysis (Cont.): for cylindrical shell roofs, 10-16 check on, 233-237 with edge beams, 205-209, 232-237 multiple barrel, 210-212, 237-238 with prestressed edge beams, 209-210 single barrel, 184-205, 228-232 for domes, 106-137 finite-element, 136-137 rigidly supported, 129-136 ring and wall supported, 150-153 ring supported, 143-146 wall supported, 148-149, 160, 165-166 for folded plates, 291-296 continuous over three supports, 307-310 with prestressing, 304-306 general method of, 36-37 Anderson, B. G., 43 Anticlastic shells, 38 Apeland, K., 289 Arches, 29, 184, 197, 214-215 cylindrical shell roofs considered as, 13-14, 17, 19-20, 218-225 domes compared to, 5-6, 8, 10 effect of, on cylindrical shell reinforcement, 255-256 elliptical paraboloids considered as, 33, 285 - 286hyperbolic paraboloids considered as, 24-26, 28-30, 267-268, 276 (See also Transverse frames) Ardeer tower, England, 322-323 Arup, O. N., 344 Assumptions (see Simplifications) Astrodome, Houston, 339, 343 (See also Domes)

B. P. Gas Station roofs, Switzerland, 339

Domes (Cont.): Leipzig market hall, 9, 10, 16 membrane theory for (see Membrane theory, for domes of arbitrary form) Pantheon, Rome, 10 reinforcements in (see Reinforcement, in domes) St. Peter's Basilica, Rome, 9, 10 segments of, 106, 108 spherical, 110-115 bending equations for, 126-129 concentrated loads on, 114-115 edge loads on, 129 pressure loads on, 113, 135-136 with skylight opening, 114-115 temperature change in, 134-135 uniform surface loads on, 110-112, 121-123, 130-135 uniform vertical loads on, 112-113 unsymmetrical loads on, 135-136 with variation in thickness, 113-114, 153-159 sports palaces, Rome, 331-332, 343-344 Superdome, New Orleans, 10, 339, 343 Zeiss planetarium, Jena, 7, 9, 10 Donnell, L. H., 198, 203-205, 216 Dumitrescu, J. A., 105 Dyckerhoff and Widmann A. G., 7, 8, 15, 16, 39 Dywidag-Halle, Düsseldorf, 10 Earthquake loading (see Seismic loading) Edge beams, 184-185, 205-209, 215 for folded plates, 298, 303-305 for multiple barrels, 210-212 prestressed, 209-210, 246, 304-305 reinforcement, 245-247, 253-254, 303 for single barrels, 232-236 Edge displacements: of circular cylindrical shell walls, 70-72, 77-78, 81 of cylindrical shell roofs, 191-195, 360-361 of domes, 125-126, 129-132, 136 Elliptical paraboloids, 32-33, 283-289 membrane theory of, 258, 283-289 Elliptical shells: of rotation, 116-123 of translation (see Elliptical paraboloids) Elms, D. G., 103, 105 Equilibrium equations, 362

(See also Bending theory; Membrane theory) Erikson, K., 104 Eschmann factory, Switzerland, 335 Esquillon, N., 39 Extensional rigidity, 74, 314, 363 Faber, D., 43, 289 Federal Technical Institute, Zurich, 7 Ferrybridge, England, cooling towers at, 320 - 322Fialkow, M. N., 257, 307, 310 Fidler, R., 320, 329 Finsterwalder, U., 11, 12, 14-16, 18, 21, 35, 39, 42, 203, 216, 324, 330 Fixed end moments: for circular slabs, 81, 82 for shell walls, 87, 89 Fletcher, B., 41 Flexural rigidity, 5, 74, 314, 363 Flexural theory, ordinary (simple): for cylindrical shell roofs, 218-219 for edge beams, 205-209 for folded plates, 293, 295 Flügge, W., 16, 18, 103, 105, 203, 205, 216, 289 Föppl, A., 11 Folded plates, 21-22, 291-310 analysis for (see Analysis, for folded plates) behavior of, 294, 296-303, 306-310 bending theory for, 293, 295 comparison of, with cylindrical shell roofs, 22, 302-303 continuous over three supports, 307-310 cross section, choice of, 296-298 definition of, 291-296 more rigorous analysis for, 294 Northlight, 292-293 prestressing in, 304-306 principal stresses in, 300-301 reinforcement for, 303 simplification for, by slab-beam approximation, 291, 293-296 span-to-depth ratio, choice of, 296 - 298stress distribution for, 299-302, 305 stress trajectories for, 301 thickness, choice of, 298 Force-strain equation, 363 Frame analysis, 36–37 (See also Transverse frames) Frankfurt market hall, 16 Freyssinet, E., 15, 35, 39, 330, 332

Gaafar, I., 310 Gaussian curvature, 38, 106, 258, 262 Gavlord, C. N., 310 Gaylord, E. H., Jr., 310 Geckeler approximation (see Simplifications) Geckeler, J. W., 7-11, 14, 41, 42 Gerasimenko, P. V., 310 Gere, J. M., 328 Ghent (Gent) University, 320 Gibson, J. E., 185, 198, 204, 216 Girkmann, K., 104, 137, 183, 310 Golberg, J. E., 138, 294, 310 Gopalacharyulu, S., 328 Gould, P. L., 105 Gray, N., 43 Groined vaults: air terminal, St. Louis, 268, 272, 333 Paris CNIT shell, 39, 40 (See also Hyperbolic paraboloids)

Hahn, M. L., 24, 43

- Hanna, M. M., 183 Hannah, I. W., 321, 322
- Harris, H. G., 329
- Hayden Planetarium, New York, 16
- Hayman, B., 318, 328
- Hayward, D. 345
- Hedgren, A. W., Jr., 257, 307

Heimberg tennis court roof, Switzerland, 336

- Hellmuth, Yamasaki, and Leinweber, 333
- Henrico County, Virginia, roof failure, 325, 328
- Hershey arena, Pennsylvania, 17, 18
- Hershey Chocolate Company, 17

Hertwig, A., 41

- Holand, L., 203-205, 216
- Homogeneity, assumption for concrete, 363
- Hooke's law, 206
- Hoop forces, 6-7, 111

Hyperbolic paraboloids, 22–32, 258–289, 325–328, 331–332, 341

- Camoletti house roof, 331, 333
- cantilever-type, 25-28, 331-332

gabled, 28-29, 272-283, 325-328, 331-332

Denver shell, 276–277, 283, 325, 328 Henrico County, Virginia, roof failure, 325, 328

groined vaults, 29-32, 40, 265-272, 331-332

inverted umbrellas, 26-28

Berenplaat Filter Building roof, 27, 333

Hyperbolic paraboloids (Cont.): membrane theory of, 258-259 with parabolic boundaries, 263-272, 287 with straight-line boundaries, 272-283 geometry of, 272-274 uniform horizontal loads on, 275-283 uniform surface loads on, 276-283 Hyperbolic shells: of rotation, 44, 62-70 of translation (see Hyperbolic paraboloids) Hyperboloids, 62-70, 99-103, 179-182, 316-318, 321-324 Trojan Tower (see Cooling towers, Trojan Tower)

Institute of Technology, Munich, 11, 15
Intermediate-barrel cylindrical shells, 185
International Association for Bridge and Structural Engineers (IABSE), Congress of the, 21
International Association for Shell Structures (IASS), 35, 321
International Federation of Prestressing, Second Congress of the, 34
Isler, H., 34, 35, 43, 330-332, 334-339, 344,

Zarzuela roof, 331-333

345 Isotropy, assumptions for concrete, 362

Jenkins, R. S., 198, 203, 216 Joedicke, J., 34, 41–43, 332, 344 Johns, D. J., 316, 318, 319, 328 Johnson, C. P., 215–217 Johnston, B. G., 217

Kabir, A. F., 329
Kalinka, J. E., 16, 18, 42
Kemp, K. D., 323, 329
Ketchum, M., 280–281, 290, 328
Kingdome, Seattle, 10, 332, 334, 339–344
compared to Montreal Olympic Stadium, 332–333, 341–343
(See also Domes)
Kohnke, R., 41
Kunderpi, P. S., 328
Kunz, C. J., 344

Larrabee, R. D., 105 Leipzig market hall, 9, 10, 16 Lenzlenger Sons Company building, Switzerland, 338 Leve, H. L., 294, 310 Limestone, Maine, hangar, 20 Linear elastic behavior, 71-75, 124-129, 193-201, 311-314, 363 Long-barrel cylindrical shells, 12-14, 18-19, 185, 191, 204-205, 210, 218, 229, 293 Loughborough University, England, 318 Lundgren, H., 205, 218, 219, 256 MacNamee, J. J., 203, 217 Maillart, R., 4, 5, 21, 22, 35, 39, 43, 330-333, 338, 341 Mark, R., 105, 257 Medwadowski, S. J., 328 Meissner, E., 7, 8 Membrane theory, 4, 36, 362-363 for cylindrical shell roofs, 186-195, 228 for domes of arbitrary form, 108-110, 123 - 126conical, 120 conoidal, 115-116 elliptical, 116-120 spherical, 110-115 of elliptical paraboloids, 258, 283-289 general, for translation shells, 259-263 of hyperbolic paraboloids, 258-259 for shell walls: circular cylindrical, 44-55, 70-72 conical, 55-62 hyperbolic, 62-70 Menn, C., 338 Meridian plane, 106 Meridional forces, 6-7, 107, 110 Michalos, J., 217 Middle surface of shell, 3, 362 Middletown, Pennsylvania, warehouse, 19, 218, 227 Models: of concrete, 10-11, 18-19, 244-249, 306-307, 320-321, 324-327 using physical analogies, 34-35, 334-336 in wind tunnels, 316, 318-320 Modulus of elasticity, 5, 316-318, 363 Modulus of rigidity, 71, 193, 317-318, 363 Molke, E. C., 42 Moment area equations, 90 Moment distribution for shell walls with slabs. 84-86 Moments, bending (see Stress couples)

Montreal Olympic Stadium, 41, 332, 333, 341-343 Müller, G., 329 Multiple-barrel shells, 199, 210–212, 237-238, 293 Mungan, I., 319, 329 Nagy, D. A., 328 National Physical Laboratories, England, 320 Nervi, P. L., 35, 39, 330-333, 338, 344 Ngo, De, 310 Niemann, H. J., 52, 104 Northlight folded plates, 292-293 Novozhilov, V. V., 137 O'Neill, P. G. G., 329 Örebro water tank, Sweden, 59, 61 Ostenfeld, K., 344 Pantheon, Rome, 10 Parabolic cylinders, 258 Paraboloid of revolution, 285 (See also Elliptical paraboloids; Hyperbolic paraboloids) Parallel circle, 106 Paris CNIT shell, 39, 40 Parme, A. L., 21, 24, 32, 43, 137, 138, 203, 257, 290 Peters, H. L., 104 Petry, W., 21, 43 Physical anologies for shell design (see Shell forms, structural) Plates, 82, 198-199 (See also Folded plates; Slabs) Poisson's ratio, 5, 193, 294, 363 Popov, E. P., 328 Portland Cement Association, 16, 21, 24, 66, 181

Potential function (see Stress function)

Pressure vessels (see Shell walls; Tanks)

Prestressed tanks, 153

typical dimensions for, 154-155 typical reinforcement for, 168, 176

Prestressing:

on circular rings, 146–148, 153–166, 170–171

in edge beams, 209–210, 246, 304–305 equivalent uniform load from, 210 in folded plates, 304–305 initial conditions with, 165–166

on shell walls, 171–174

Principal stresses: in cylindrical shell roofs, 250–252 in folded plates, 300–301 in translation shells, 275–278 Pucher, A., 289 Pultar, M., 307, 310 Quist, 333

Rathe, J., 329 Reinforcement: in circular rings, 168, 171 in cylindrical shell roofs, 225-228 for bending at support, 255-256 minimum, 255 for principal tension, 250-252 for transverse bending, 252 in domes: for hoop tension, 166-167 for meridional bending, 167-170 minimum, 167 in edge beams, 245-246, 253-254 in folded plates, 303 in shell walls: for bending, 174-175 hinged-base, 175-177 for ring tension, 171-174 Reiss, M., 310 Reissner, H., 4, 5, 41 Research-Cottrell, Inc., 66 Revolution, shells of (see Rotation shells) Ribless shells, 19, 246, 256 Riera, J. D., 310 Rish, R. F., 328 Rivergate exhibition hall, New Orleans, 340 Roberts and Schaefer Company, Inc., 16, 18, 20, 21, 39 Rotation shells, 28, 44, 62-70, 106, 116 - 120Rüsch, H., 15, 16, 42

Saddle surfaces (*see* Hyperbolic paraboloids) St. Louis air terminal, 268, 272, 333 St. Peter's Basilica, Rome, 9, 10 Saint-Venant, principle of, 8, 75 Salvadori, M. G., 21, 289 Samevedam, G., 328 San Diego hangar, 20 Scanlan, R., 52, 104 Schnobrich, W. C., 280–283, 290, 328 Schorer, H., 18, 21, 42, 203, 205, 216 Schwedler, J., 5 Scordelis, A. C., 31, 43, 215–217, 240, 257, 267, 290, 303, 306, 310, 321, 328, 329 Seidensticker, F. W., 18 Seismic loading: on circular cylindrical shell walls, 49 - 52on conical shell walls, 62 on hyperbolic shell walls, 69 Shaaban, A., 280-281, 290, 328 Shallow-shell theory, 363 for cylindrical shell roofs, 195-203, 205 for translation shells, 258 Shear modulus (see Modulus of rigidity) Shell bending stiffness (see Flexural rigidity) Shell extensional stiffness (see Extensional rigidity) Shell flexural stiffness (see Flexural rigidity) Shell forms: geometrical, 35 (See also Barrel shells; Circular cylinders; Cones; Cooling towers; Cylindrical shell roofs; Domes; Elliptical paraboloids; Folded plates; Hyperbolic paraboloids; Hyperboloids; Tanks) sculptural, 35 Sydney Opera House, 41, 332 structural (designed by physical analogies), 35 B. P. Gas Station roofs, Switzerland, 339 Bürgi Garden Center, Switzerland, 336 Eschmann factory, Switzerland, 335 Heimberg tennis court roof, Switzerland, 336 Lenzlenger Sons Company building, Switzerland, 338 Sicli Building, Switzerland, 337 Shell ring stiffness, 5, 75, 314 Shell roofs (see Cylindrical shell roofs) Shell slope, 227-228, 296 Shell thickness: choice of, 225-227, 298 variation in (see Variation in shell thickness) Shell walls: behavior of, 75-76 circular cylindrical, 44-55, 70-78, 87, 165 analysis for (see Analysis, for circular cylindrical shell walls) behavior under wind, 92-99 bending in, 72-78 edge displacements of, 70-72, 77-78, 81

Shell walls, circular cylindrical (Cont.): edge loads on, 77, 81 moment distribution for, with slabs, 84 - 86pressure loads on, 49-55 prestressing for, 147-149, 171-174 reinforcement (see Reinforcement, in shell walls) conical, 55-62 gravity loads on, 57-59 pressure loads on, 59-62 hyperbolic, 62-70 gravity loads on, 65-68 pressure loads on, 68-70 Short-barrel cylindrical shells, 17, 19-20, 101, 185-186, 201, 205, 211, 213-214 Sicli Building, Switzerland, 337 Silverman, I. K., 18 Simiu, E., 104 Simplifications, 2-4 for circular cylindrical shell walls, 4-5, 75 - 76with variable thickness, 74-75 for circular foundation slab, 89-92 for cylindrical shell roofs, 11-12 by beam-arch approximation, 218-225, 229, 240 of edge beams by neglecting torsion, 235by shallow shell theory, 198-199 at transverse frames, 185, 202, 212-215, 246, 248 by various theories, 203-205 for elliptic paraboloids, 32-33 for folded-plate analysis by slab-beam approximation, 22, 293 for groined vaults, 29-32 for hinged-base wall reinforcement, 175 - 177for hyperbolic paraboloids, 22-29 for hyperboloids, 65-69 for multiple-barrel shells, 199, 210-211 for radius of circular rings, 142 for spherical domes, 5-7 with variable thickness, 153-157 under wind load, 135-136 of uniform function approximated by sine curve, 190-192, 228-229 (See also Membrane theory) Simpson, H., 310 Slab-beam analysis for folded plates, 293 - 296Slabs: circular roof, analysis of, 78-86

Slabs (Cont.): elementary transverse for folded plates, 293 - 296foundation for shell walls, 87-92 (See also Plates) Small deflection theory, 311 Smith, S., 105 Sollenberger, N. J., 52, 104 Spherical shells (see Domes, spherical) Statically-indeterminate analysis for thin shell systems (see Analysis) Stiffness factors: for circular cylindrical shell walls, 85-86 for circular slabs, 86 Strain in thin shells, 71, 124, 193, 317, 362 Stress couples, 3, 72, 128, 197, 362 Strain-displacement equations, 70, 123-124, 128, 193, 197, 363 Stress function, 199, 262-264, 266, 285-286 Stress resultants, 3, 45, 72, 128, 197, 362 Stress-strain equations, 71, 363 Stresses (see Principal stresses) Structural Analysis Program (SAP), 215, 240 Structural Engineering Handbook, 291, 310 Superdome, New Orleans, 10, 339, 343 Sydney Opera House, Australia, 41, 332 Synclastic shells, 38 Taillibert, R., 339 Tanks: with circular roof slabs, 76-86 conical. 44. 59-61 with domed roofs, 154-155, 177 with fixed base, 87, 89

with hinged base, 87-88

(See also Shell walls)

330-333, 344, 345

on dome-wall system, 165

Models, of concrete)

definition of, 3-5, 304, 362

Thin shell theory, 362-363

in shell walls, 103-104, 323

Tests on cylindrical concrete shells (see

Temperature variations:

on domes, 134-135

165

Thin shells:

with partially fixed base, 89-92

prestressed (see Prestressed tanks)

Technological University, Vienna, 19

Tedesko, A., 15-19, 39, 42, 256, 290, 328,

on dome-ring-wall system, 160-161, 163,

Thin shells (Cont.): MIT conference on, 24 strain in, 71, 124, 193, 317, 362 Thom, H. C. S., 104 Thürlimann, B., 217 Timoshenko, S. P., 105, 137, 183, 216, 328 Torroja, E., 35, 69, 105, 330, 338, 344 Tottenham, H., 43 Translation shells: definitions of, 38, 258-259 general membrane theory for, 259-263 simplified analyses of, 22-33 (See also Elliptical paraboloids; Hyperbolic paraboloids) Transverse frames, 184, 202 interaction with shell, 212-214 as T beams, 212 (See also Arches; Ribless shells) Trojan Tower, Oregon (see Cooling towers, Trojan Tower) Truss analogy, 37 Turin exhibition halls, 333 Twist of surface, 23, 261-262, 287 change of, 197, 362

Ultimate load behavior, 169–171, 174–175, 180–181, 244–249, 306–307, 311, 321, 324–327 University of Illinois, 16

Vandepitte, D., 320, 325, 329
Van Koten, H., 257
Van Leeuwen, J., 257
Van Riel, A. C., 257
Variation in shell thickness: for domes, 113-114, 153-156
for shell walls, 72, 74-75, 155, 177-178
Veronda, D. R., 329
Vlasov, V. Z., 198, 203, 216 Volume changes (see Temperature variations) von Emperger, F., 4, 5, 9, 41 Walls (see Shell walls) Wang, Y-S., 328 Warping, 279 (See also Twist of surface) Water tanks (see Tanks) Water towers, 59-61, 69 Wayss, G, A., 4, 5, 41 Wayss & Freytag A. G., 21, 22 Weingarten, V. I., 329 Weiskopf & Pickworth, Inc., 16 Weymeis, G., 329 Whitney, C. S., 20, 21, 43 Wiita-Dworkin, C., 328 Wilson, E. L., 215 Wind loads: on circular cylindrical shell walls, 52 - 55on conical shell walls, 61-62 on domes, 135–136 Wind tunnels, models in, 316, 318-320 Witmer, D. P., 42 Woinowsky-Krieger, S., 105, 137, 183, 216 Wu, S-C., 105 Wuezkowski, R., 41

Yamasaki, M., 333 Yitzhaki, D., 293, 295, 310 Young's modulus, 316-318

Zarzuela roof, 331–333 Zeiss Company, 7, 10 Zeiss-Dywidag method, 10, 15, 16, 18 Zeiss planetarium, Jena, 7, 9, 10 Zerna, W., 104 Zurich Cement Hall, 331, 333 Zweig, A., 257